Evaluation of Applicant's responses to EPA's questions of the AoR Delineation Modeling Approach in Carbon TerraVault's Monterey Formation 26R Class VI Permit Application

This area of review (AoR) delineation modeling evaluation report for the proposed Carbon TerraVault (CTV) Elk Hills 26R Class VI geologic sequestration project summarizes EPA's evaluation of the modeling performed by CTV as described in the Area of Review and Corrective Action Plan (AoR CA), which is Attachment B to CTV's November 5, 2021 permit application, and associated files submitted to the AoR and Corrective Action Module of the GSDT. This review also addresses modeling-relevant site characterization information in the permit application narrative and in the Post-Injection Site Care (PISC) and Site Closure Plan (Attachment E). Clarifying questions for CTV and requests for supplemental information are provided within the text below

Please note that modifications to the model parameters may be needed if pre-opperational testing yields results that are significantly different than the model inputs described in the initial permit application. On June 2, 2022 CTV responded to EPA's March 31, 2022 questions (*blue, italic text*) and provided an updated AoR and Corrective Action Plan dated May 31, 2022; EPA's evaluation of the responses is provided in red below. Requests for revisions and additional information are presented in ***red, bold, and italic*** below. Previous responses that require no further information are not included in this enclosure.

Evaluation of the Geomodel

Geomechanical properties

The geomechanical properties of the Monterey Formation 26R reservoir and Reef Ridge Shale confining zone were derived from compressional sonic data from 11 wells and MICP measurements from Well 355X-30R. Borehole breakout data from the EHOF and literature reviews also aided in characterizing fracture behavior. A corresponding geomechanical model was generated to assess the failure pressures for the reservoir and confining zone. CTV included relevant discussion concerning geomechanical modeling and properties in the permit application narrative; please also see the geologic site characterization report for discussion.

A summary of fracture pressure data for the Monterey Formation 26R reservoir is provided in Table 6 of the AoR CA, which is replicated below. The applicant states that injection pressure will be below 90% of the Monterey Formation 26R fracture gradient at the base of the Reef Ridge Shale in the AoR (6,826.6 ft TVD as seen in Table 7 of the AoR CA, replicated below). The planned maximum subsurface wellbore injection pressure for the project is 4,900 psi.

The elevation of the top of the perforated interval in Table 7 is inconsistent with the depths on a well diagram for Well 373-35R, which was provided in a confidential file that contains schematics for the wells in the AoR. Accounting for the elevation of the well relative to mean sea level (1,329 ft), the top of the perforated interval would equate to 6,813 ft TVD. A similar discrepancy exists in Table 5, which shows the top and bottom of the perforated intervals, which would equate to 6,813 to 7,618 TVD.

Table 6 of the AoR CA: Summary of the fracture pressure data for the Monterey Formation 26R reservoir at the 373-35R well.

Interval	Breakdown Fracture Gradient PSI/foot	Fracture Pressure (PSI) at base of Reef Ridge Shale (6826.6 feet TVD)
Monterey Formation 26R	1.03	7,031

Table 7 of the AoR CA: Injection pressure details

Injection Pressure Details	**Injection Well 1 373-35R**
Depth corresponding to maximum injection pressure (ft TVD)	6,826.6
Breakdown Fracture gradient (psi/ft)	1.03
Calculated maximum injection pressure at the top of the perforated interval (psi)	7,031
Maximum injection pressure (90% of fracture pressure) (psi)	6,327.9
Elevation at the top of the perforated interval (ft MSL)	-5,484
Planned maximum injection pressure/ gradient (top of perforations)	4,900 / 0.71

Objectives for Pre-Operational Testing:

- *Confirm the fracture pressure of the injection and confining zones, i.e., by performing an SRT in each zone.*

Geomodel – 3D model grid resolution and discretization

The Petrel static geomodel was used as the framework for the GEM numerical model. The geo-cellular grid is uniformly spaced throughout a 3.7 square mile area with a cell size of 190 ft x 150 ft. The model grid is oriented at 18 degrees, which corresponds to both the structural trend of the anticline and the depositional environment. The model boundaries were selected based on plume extent and the edges of the Monterey Formation 26R reservoir. CTV submitted an example image of the geo-cellular grid to the GSDT in a file titled 26R—Grid--Image.jpg. The image demonstrates uniform geo-cellular spacing, a northwest-southeast orientation, and a consistent structural trend, deepening towards the southwest.

The reservoir was separated into twelve zones and 27 layers and an average grid cell height of 117 ft (Figure 3 in AoR CA). Grid resolution was idealized based on simulation run-time and retaining reservoir heterogeneity. The grid files are claimed as confidential business information (CBI) and were not submitted to the GSDT (but were provided to EPA by a separate means).

Questions/Requests for the Applicant:

- *Please discuss the vertical layers (stratigraphy) that were included in the model and why cell size height may vary between vertical layers. CTV responded that these layers were selected to*

represent the geology and allow for adequate resolution of the reservoir and optimize the computational modeling run-times. Finer grids will prevent adequate run times and larger grids will not properly model the plume. The response addresses the variation among the cell sizes, and the AoR CA generally describes how site-specific information was used to develop the model. EPA requests additional detail and description about how the model layers were developed to improve the modeling discussion.

- *Please label the vertical layers shown in Figure 3 of the AoR CA, especially the injection and confining layers. Additionally, please show the location of CTV's proposed Class VI injection wells on the inset base map and cross-sectional views. The top and bottom of the injection zone have been labelled; however, individual layers used in the modeling have not been labeled. The inset map has been updated with the injectors and AoR. Labeling the 12 individual sands and their relationship to the collected geologic data would enhance the model documentation and better clarify how site-specific data informed the model development.*

Follow-up Questions/Requests for the Applicant:

- ***Please provide an expanded discussion of the relevant properties of each of the 12 zones within the reservoir, and how site-specific geologic data informed model development.***
- ***What do each of the 27 layers in the model represent, i.e., are they variations within the 12 modeled layers of the 26R reservoir?***
- ***Please label the 12 individual sands in relevant figures.***

Evaluation of the Computational Model Design

The applicant's discussion of computational model design includes but is not limited to: subsurface phase properties and behavior, CO_2 plume size and extent, boundary and initial conditions, timeframe and time steps, operational information, model calibration and sensitivity analysis, and injection zone storage capacity. EPA considers the applicant's discussion of the computational model design and associated components to be appropriate and relatively complete, however there are several outstanding questions that need to be addressed in order to consider the material in this section sufficient, as described in the sub-headings, below.

Relative permeability and capillary pressure curves

Gas, oil, and water are all present in the Monterey Formation 26R Reservoir. Contact depths have been derived from open-hole logs, production analysis, and history matching, and saturations have been assumed; however, the AoR CA does not provide the basis for the assumptions. With all three phases present in the reservoir, three-phase relative permeability relationships were used in the computational model to characterize the flow of each phase. To determine three-phase relative permeability, two sets of two-phase relative permeability data are needed: water-oil and gas-oil relative permeability. The two-phase relative permeability relationships allow the determination of Krw, Krow, Krg, and Krog as a function of water or liquid saturation. Core flood and MICP data were used to determine the two-phase relative permeability relationships. Figure 7 of the AoR CA presents the relative permeability curves used in the computational modeling.

Potential Pathways for Fluid Movement

Faults

CTV included relevant discussion concerning fault stability in the permit application narrative. Please also see the "Representation of Site Geologic Features" and "Fault Stability" sections above, and the geologic site characterization report for discussion.

Wells in the AoR

The AoR CA states that 204 wells in the AoR penetrate the Reef Ridge Shale confining zone and Monterey Formation 26R reservoir. These wells are tabulated in Table 8 of the AoR CA, and presented in a map in Figure 13. Appendix 1 to the AoR CA provides information about the 204 wells in the AoR, including well name, API number, type, status, spud date, and locational information (e.g., latitude/longitude and surface coordinates). However, no depth or completion formation is provided, so it is unclear how many of the wells penetrate the entire Reef Ridge Shale, and if they are accounted for in the computational model. Additional discussion regarding wells in the AoR is presented under "Corrective Action on Wells in the AoR," below.

Calculation of critical pressure

CTV submitted critical pressure information to the GSDT in a file titled "Critical—Pressure—Calculation.PDF." However, they did not conduct a critical pressure calculation due to the absence of a USDW within the modeled AoR. (The applicant asserts that the Upper Tulare Formation is an unsaturated zone, and the Lower Tulare Formation is an exempt aquifer.) The permit application asserts that the final pressure of the Monterey Formation 26R reservoir will be at or below the initial reservoir pressure of 3,250 psi, ensuring that post-injection conditions replicate those of initial conditions to the extent possible. Therefore, the AoR is based on the extent of the modeled CO_2 plume.

Questions/Requests for the Applicant:

- *Do any of the 204 wells in the AoR penetrate the entire Reef Ridge Shale? If so, please explain how they are accounted for in the geomodel. CTV responded that the 204 wells that penetrate the Reef Ridge are used to define the structure of the Reef Ridge Shale. However, it is still unclear whether, following pre-operational plugging activities, any wells will penetrate the entirety of the confining zone. Any such wells should be addressed in documentation of the modeling approach. (See also EPA's follow-up questions under Corrective Action on Wells in the AoR, below.)*

Objectives for Pre-Operational Testing:

- *If, based on additional information, the Upper Tulare is determined to be a USDW within the AoR of the 26R project, please provide documentation of the critical pressure calculation. CTV submitted a document ("26R Critical Pressure.pdf") detailing a potential critical pressure calculation, assuming the Upper Tulare is saturated. Whether or not this satisfies the pre-operational testing objective, depends on the results of water quality analyses of the Upper Tulare.*

Follow-up Questions/Requests for the Applicant:

- ***Please explain how any wells in the AoR that penetrate the confining zone and will not be plugged, side tracked, or converted to an injection or monitoring well are accounted for in the geomodel as potential pathways of fluid movement.***

Representation of Fluid Properties

Because a baseline injectate analysis has not yet been performed, limited information about the CO_2 stream is available and relevant CO_2 injectate fluid properties for the numerical modeling are not included in the AoR CA. The applicant did not submit an operating plan for the proposed wells with this information. Additionally, the applicant did not include reactive transport modeling as part of the overall modeling effort. It appears this might be due to the dominant quartz/feldspar mineralogic framework of the reservoir, as noted in the permit application narrative. However, an explanation regarding the lack of reactive transport modeling is needed.

Objectives for Pre-Operational Testing:

- *Confirm that the properties of the CO_2 stream based on pre-operational injectate sampling are consistent with the model inputs.*

Corrective Action on Wells in the AoR

The AoR CA says that documentation of the 204 wells in the AoR that penetrate the Reef Ridge Shale confining zone is provided in Appendix 1, which is an Excel file (AoR—Well--List) containing the name, surface location, and status of 204 wells, but it does not contain information on drill date, type, and depth to Reef Ridge Shale confining zone that is required at 40 CFR 146.84 (c)(2). This information is summarized on Table 8 of the AoR CA, which indicates that 36 of the 204 wells are plugged (which corresponds to information in the Excel file). Figure 13 of the AoR CA shows a map view of the 204 wells that penetrate the Reef Ridge Shale confining layer and Monterey 26R Formation. The applicant states that these wells were reviewed for corrective action.

The applicant says that the determination that all 204 wells in the AoR penetrate the confining zone was made by reviewing open hole logs and deviation surveys of each well. The AoR CA plan says that well condition, mechanical integrity, and data completeness is routinely reviewed with CalGEM. The wells located within the AoR were last reviewed in Q4 of 2021.

Table 9 of the AoR CA indicates that 168 wells will be abandoned prior to injection: one will be repurposed as a CO_2 injector, three wells will be repurposed as monitoring wells; and the remaining 164 wells require standard plugging procedures as part of asset retirement obligations (these procedures are not described, however). It is unclear based on the text or table which wells these are and if they are the only wells that penetrate entirely through the Reef Ridge Shale, however.

The AoR CA also states (pg. 17) that all wellbores within the AoR will, if necessary, be pressure tested, abandoned, re- abandoned, monitored, or have a technical demonstration showing adequate zonal confinement prior to the commencement of CO2 injection or based on an agreed upon phased schedule post CO2 injection if conditions allow. The plan also asserts that there is no USDW present in the AoR; this statement needs to be confirmed (see EPA's geologic evaluation).

Questions/Requests for the Applicant:

- *Please clarify the statement on pg. 16 that, "with well abandonment and monitoring, the CO_2 injected will be confined to the Monterey Formation 26R reservoir." Specifically, is monitoring (rather than plugging) being considered as an approach to ensure isolation for any wells other than those to be repurposed as monitoring wells? CTV responded that well abandonment and implementation of a monitoring program will both contribute to demonstrating confinement to the Monterey Formation 26R reservoir. However, EPA needs to ascertain whether any wells that penetrate the confining zone will not be plugged prior to injection operations (or be converted to an injection or monitoring well).*
- *Please add a description of each well's type, construction, date drilled, location, depth, and record of plugging and/or completion to Appendix 1, as required at 40 CFR 146.84 (c)(2). CTV provided a document entitled "Appendix_Wellbore Table for Corrective Action Assessment_V2" (CBI). This provided the information requested. However, EPA seeks clarity on whether any of the 204 wells in the AoR penetrate the confining zone; see the questions below.*

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Follow-up Questions/Requests for the Applicant:

- ***Please explain if any of the 204 wells in the AoR penetrate the confining zone and will not be plugged, side tracked, or converted to an injection or monitoring well. If any such wells exist, please list them, and explain the monitoring that will be performed and how it will ensure that injected fluids will not move outside of the injection zone.***
- ***The updated table of wells in the AoR identifies four wells that will be converted to monitoring wells. However, the Testing and Monitoring Plan refers to three deep monitoring wells (341-27R, 328-25R and 376-36R). Please clarify (and if necessary update the Testing and Monitoring Plan and monitoring well schematics), if an additional deep monitoring well is planned.***

Triggers for AoR Reevaluations Prior to the Next Scheduled Reevaluation

On page 17, the AoR CA says that an unscheduled reevaluation of the AoR will take place if any of the following scenarios occur:

1) There are changes in operations such as an increase in injection rates, or injection pressure.

2) Differences are observed between the computational model for CO_2 plume development and observed CO_2 plume development, including unexpected changes in fluid content or pressure outside of the Monterey Formation 26R reservoir that are not related to well integrity, or reservoir pressure that does not behave as predicted with increased injection volumes.

3) Seismic events occur that indicate the presence of faults near/intersecting the confining zone; events that are larger than a 3.5 magnitude and that could be associated with CO_2 injection.

CTV will discuss any such event with the UIC Program Director to determine if an AoR reevaluation is necessary. If an unscheduled reevaluation is triggered, the AoR reevaluation procedures described in the AoR CA plan will be initiated.

Questions/Requests for the Applicant:

- *Please describe the specific injection rate and injection pressure increase CTV referenced that would necessitate an AoR reevaluation, and how such an increase would not involve an exceedance of permit limits. CTV specified that changes in pressure or injection rates outside of three standard deviations from the average will trigger an unscheduled AoR evaluation as requested. However, it is likely that injection pressures as high as three standard deviations above the permit limit would constitute a violation.*
- *Please clarify the degree of change in reservoir pressure (e.g., outside three standard deviations from the average) that would necessitate an AoR reevaluation. CTV did not specify this degree of change relative to the modeled predictions as requested.*
- *Please clarify the timing for conducting an AoR reevaluation (i.e., within 6 months) if any of the triggering events occur. CTV states that, within six months of a triggering event, CTV will discuss with the UIC Program Director whether an AoR reevaluation is required. EPA notesthat such discussions will need to commence sooner than six months after CTV becomes aware of them, and that the AoR reevaluation should be completed within six months.*

Follow-up Questions/Requests for the Applicant:

- ***Please edit the first trigger to not reference an increase in injection pressure as high as 3 standard deviations, or explain how such an increase would not be a violation of the injection pressure limit in the permit.***
- ***Please describe, in the second trigger, what degree of reservoir pressure increase relative to modeled predictions would trigger a reevaluation (or if any increase would trigger one).***
- ***Please revise the text at the bottom of page 21 to read, "CTV will discuss any such events with the UIC Program Director as soon as possible to determine if an AoR re-evaluation is required. If an unscheduled re-evaluation is triggered, CTV will perform the steps described at the beginning of this section of the Plan within six months of the triggering event."***